A.D. 1870, 23rd November. N° 3069.

Electric Telegraph Instruments and Clocks.

(*Provisional Protection not allowed.*)

PROVISIONAL SPECIFICATION left by Sir William Thomson at the Office of the Commissioners of Patents, with his Petition, on the 23rd November 1870.

I, Sir WILLIAM THOMSON, Knight, of Glasgow College, Doctor of Law, and Professor of Natural Philosophy in the University and College of Glasgow, do hereby declare the nature of the said Invention for "IMPROVEMENTS IN ELECTRIC TELEGRAPH TRANSMITTING, RECEIVING, AND RECORDING INSTRUMENTS AND IN CLOCKS," to be as follows:—

My present Invention consists partly in improvements in the construction and design of my receiving or recording instrument (described in the Specification No. 2147, 1867), partly in appliances to that instrument, adding new functions to it, and partly in methods for sending messages.

1. My first improvement consists in a better form and disposition of the light receiving coil and of the magnet used to produce the magnetic field in which it moves. For brevity I shall call these parts of the apparatus the signal coil and the signal magnet respectively. I now give the coil the symmetrical form of a long rectangle, and support it so that it is moveable about the middle line parallel to the long sides;

I place it with the long straight side of the skein of wire in the magnetic field. I effect this by stopping the two poles of the signal magnet at such a distance from one another that two sides of the coil or skein can be introduced between them instead of one side only. I place inside the coil or skein a fixed soft iron core. The space between the iron core and the magnet is as narrow as is consistent with freedom of oscillation for the coil. By this arrangement I obtain the following advantages :—The force with which the coil is deflected by any given current is increased, because it is now only the short portions of the coil at the top and bottom that are not effectively influenced by the electro-magnetic force. The length of the top and bottom portions of the coil can by the new arrangement be greatly reduced, and so the mass and moment of inertia much diminished. A better form of suspension can also be applied to the coil as now improved.

To save the expense of maintaining an electric current constantly through the coil of an electro-magnet with a soft iron core I make the signal magnet a retentive electro-magnet according to the following plan :—The core is either altogether of steel or in part of steel, and it is wound round with a coil ready to magnetize it powerfully in the beginning, and to restore the magnetism at any time afterwards in case of its having become too weak, whether through rough usage in travelling, or change of climate, or lapse of time. I also provide (§ 44) a suitable battery to give for an instant occasionally great magnetizing power.

2. My next improvement consists in peculiar arrangements for applying electro-magnetic induction to diminish injurious oscillations. This effect, which I will call damping, is obtained by taking advantage of induction between the moving coil and the magnet. It is well known that a piece of copper or other conducting material moving in the neighbourhood of a magnet experiences a resistance due to currents induced in its mass. This effect becomes very sensible in the coil arranged as described above if shunted and tends to check its motion somewhat as does an air vane, but much more effectively. This inductive damping may easily be pushed so far that after a sudden change of position the coil shall come to rest in its new position without oscillations, which enables the coil more truly to follow very sudden changes in the received current, such as are experienced in ordinary land telegraphs.

One method of producing the effect was described in my former Specification, No. 2147 of 1867. It consists in applying a shunt to the receiving coil. I now provide a set of shunt coils of graduated resistances with a convenient arrangement, whether by a plug or slide, for applying the desired degree of shunt to the moveable coil. By this means the exact amount of damping suitable to each speed of signal can be obtained. This system of graduated shunts is also convenient for assisting in the adjustment of the sensibility of the instrument; but in many cases it is better to confine the use of the shunts chiefly to the adjustment of the damping effect, and to adjust the range of signals by regulating the battery power employed, or by varying the directive agency given by the suspension of the coil.

Another method is to construct the coil of fine bare wire, the ordinary silk covering being wholly omitted. The effect of this is to partially short circuit the coil by contact between successive layers; this partial short circuiting produces the peculiar inductive action desired, and the absence of the silk diminishes the mass of the coil, which is a subsidiary advantage. If the coil is short circuited to an inconveniently great degree by the use of bare wire, so as to diminish unduly the sensibility of the instrument to receive currents, part or the whole of the coil may be very slightly silk covered, or otherwise coated with a thin layer of matter of low conductivity, so as to leave some degree of short circuiting, but not too much.

3. My next improvement consists in attaching the soft iron core with the attachment of the wires, cords, or fibres bearing the moving coil, and the syphon to a single supporting plate screwed to a stout metal plate rigidly connected with the great magnet. This support can readily be removed for the examination, adjustment, or repair of any of the delicate parts. This support with soft iron core, suspended coil, connecting fibre, and suspended syphon, all mounted, it may be kept ready in duplicate to replace almost instantly that which has been in use in case of the syphon clogging or other accident.

4. My next improvement consists in adopting for suspension of the moveable coil the double bifilar suspension described in my Specification No. 329, 1858 (fourth part). I have added to the suspension, as there described, an adjustment by which the tension of each fibre can be separately increased or diminished. Each fibre is attached to a small drum borne by pivots attached to a spring, so that the required tension

is obtained by easy adjustments, and maintained with sufficient constancy in the use of the instrument. I have also added a method of increasing or diminishing at will the distance between the fibres at the point of support.

5. My next improvement also relates to the suspension of the moveable coil. It is more particularly useful for cases such as applications to signals received through long submarine cables, in which extremely rapid directive agency is not required. It consists in giving a directive power by the tortional elasticity of two tightly stretched wires, by means of which the moveable coil is pulled in opposite directions and supported. The wires serve also as electrodes between fixed terminals and the ends of the moveable coil. Appliances are introduced to allow one or both of these wires to be shortened or turned round the axis of the coil's motion, so as to adjust the directive force and the undiflected position of the coil to the fixed or varying requirements of any case. Particular appliances by which I find it convenient to attain this object are as follows:—One of the stretched torsion wires is wound round a small drum or pully whose bearings are attached to a sliding piece capable of being unclamped, moved parallel to the line of the axis of the moveable coil's motion, and clamped again. By turning round the drum in one direction or the other, and leaving it clamped or held fast by friction, the part of the wire submitted to torsion is adjusted to the length suitable for the degree of directive force required. The other torsion wire is kept tight by a spring attached to a shaft moveable round an axis, which is by proper mechanism adjusted accurately to be in line with the axis of the coil's motion. This second torsion wire is made strong enough to be capable of balancing by its torsional elasticity the greatest deflecting couple due to earth currents or other disturbing causes which may have to be held in check in the use of the instrument.

6. My next improvement consists in supporting the syphon on a fine wire tightly stretched by springs pulling its ends in opposite directions instead of the torsional arrangement described in my Specification of 1867, No 2147.

7. My next improvement consists in tightening the fibre which connects the syphon with the coil by applying couples to the coil and to the syphon, tending to separate the points of attachment of the two ends of the fibre. The use of torsional elasticity described in my fifth

improvement for directing the coil allows the couple required on it for the purpose to be applied to it with great facility. Similarly the couple on the syphon is applied by turning one or other of the springs which stretch the bearing wire round a pivot coaxial or approximately coaxial with the axis of the syphon's motion, but the desired couple may also be applied by aid of the milled head indicated in the diagram, Figure 4 of the Drawings attached to my former Specification referred to above.

8. My next improvement consists in better constructive details by which the marking tube (§ 9) or syphon ink bottle and connecting fibre can be more readily removed and replaced, which will be fully explained by reference to the Drawings accompanying the Complete Specification.

9. My next improvement consists in substituting for the syphon a fine tube fixed by an ink-tight fitting into the ink bottle, but having its outer end sufficiently moveable to mark the signals, and applying by any convenient hydrostatic method the proper fluid pressure to the liquid in the ink vessel to give good marking with or without the electric action or the vibrations described in my former Specification. One way of fitting the tube for this purpose is by having a small portion of the ink vessel where it is perforated by the tube of flexible or elastic material, as, for instance, thin sheet india-rubber. Another method is to cement the tube rigidly into the aperture of the ink bottle and trust to the flexibility of the tube to give the requisite degree of mobility to its outer end. If the whole tube is not firm enough for this purpose a portion of it near the ink vessel is made so, and thus an elastic joint is constituted. If in any case the mobility in the plane of the paper is found too free with a round tube greater rigidity in this plane may be given either by a stretched fibre or fibres acting on the same principle as stays in the rigging of a ship, or by making the tube of oval section. A single stay answers very well for this purpose. While giving greater effective rigidity in the plane perpendicular to the paper it will give either unchanged mobility or less mobility or greater mobility parallel to the paper, according as its fixed end is in a certain line perpendicular to the length of the tube or nearer the outer end or further from the outer end. When the single stay is used I introduce a simple mechanism by which the position of its fixed end is adjusted to give the desired mobility to the outer end of the tube and the proper tightness of the stay.

The chief advantage of this improvement is that it allows the tenth and eleventh improvements described below to be introduced. A subsidiary advantage consists in allowing the plane of the arc along which the marking end moves in virtue of the signals to be horizontal instead of vertical, as it necessarily is with the syphon if of simplest form and smallest moment of inertia attainable. The present improvement allows when desired the signals to be first shewn on the portion of the paper where it is running horizontally.

10. My next improvement consists of plans for urging liquid through the marking tube by hydrostatic pressure. In many cases the requisite pressure for good marking is that due to a few inches head of the liquid. In all such cases this pressure is most conveniently obtained by having free communication of air pressure between the atmosphere and the free surface of ink in the ink vessel, that is to say, by having the ink vessel either open or closed by a cover not perfectly air-tight. When a greater constant pressure is desired than can be easily thus obtained I use my ninth improvement and produce the requisite pressure either by gravity acting on a column of mercury or by air or other fluid pressing on the free surface of the ink, or by a piston, or by a flexible part of the ink bottle acted on by force properly applied from without. The column of mercury is preferable in respect of constancy.

11. My next improvement consists of plans for applying hydrostatic pressure to free the tube from obstructions. If the tube becomes clogged at any time so as to impair the marking the obstruction is often removeable by fluid pressure forcing the ink to flow through it. This cannot be done easily for the syphon otherwise than by the operator's sucking the lower end of it by his mouth, a delicate operation, involving considerable danger to the syphon. My ninth improvement affords various methods by which it may be done with much greater force with perfect safety to the tube and without any dexterity on the part of the operator. For instance, one of these is as follows :—I apply an air syringe of small bore to the upper part of the ink bottle, which if ordinarily open to the air is to be closed for the occasion by a proper plug or stop-cock. Any degree of air pressure required is then readily applied to the free surface of the ink. Another method is by a reservoir of mercury connected by a flexible tube to one branch of a U tube the upper portion of the other branch of which is in hydrostatic communication with the ink vessel either through the liquid itself continued to the surface of the mercury

or through a portion of air intervening. A much greater pressure than can be obtained by blowing with the mouth can be easily obtained by raising the reservoir of mercury at any time through the space of a few inches or feet. The mercury reservoir may be left ordinarily in such a position as to give the proper pressure for regular marking, but at any time (in case of suspected clogging for instance) it may be instantly raised or lowered so as to produce a largely increased or largely diminished pressure. It often happens that an obstruction can be only partially removed by forcing the ink through the tube, in such cases nitric acid or other powerful solvent forced through generally clears the obstruction perfectly away in a moment. This is most easily done by applying (with the aid of the apparatus described in § 15) nitric acid to the marking end, and drawing a very small quantity through either by a syringe acting as a drawing air pump, or by a mercury vessel lowered several inches below the level of the tube.

12. My next improvement consists in adopting my ninth improvement but substituting torsional elasticity of a long fine glass tube for the flexural elasticity of the elastic joint which I used in the 9th improvement when first testing it. This 12th improvement is most readily executed by keeping the part of the tube used for torsion tightly stretched by means of stout silk thread or fibre, pulling one end of it while the other is fixed to the ink bottle. The signalling arm may be of the same guage of glass tube as the torsional part, and continuous with it, simply bent by the glass blower to its proper transverse position. The tightening fibre should be attached at one end by cement or otherwise to the torsional part of the glass tube near the bend where the marking arm begins. To keep it constantly stretched with a proper degree of force I use a metal spring or the force of a weight acting on its other end.

13. My next improvement consists in attaching rigidly to the syphon or signalling arm a counterpoise, so that its centre of inertia may lie in the axis round which it turns. It has two advantages, (1), diminishing the tendency to irregular vibrations caused by tremors transmitted through the framework, whether from the running gear or from disturbances in the neighbourhood, such as are experienced when the instrument is used in a crowded city, in a factory, or at sea; (2), checking the disturbance of siguals produced by the greater motions of the ship when the instrument is used at sea.

14. My next improvement consists in a mechanism for readily at any time increasing or diminishing the distance between the marking end of the signalling arm and the paper to secure good marking, and to admit the application of the vessel of water or other solvent to the marking end of the syphon or tube as described in my eleventh improvement.

15. My next improvement consists in proper mechanism and appliances for readily substituting a vessel of water or nitric acid or other suitable solvent in place of the ink bottle, and for applying to the marking end a vessel of such solvent, or a receptacle to receive ink flowing when the instrument is out of use; by this means clogging not removeable by hydrostatic pressure (§ 11) may be readily and speedily dissolved away, and the instrument again set in action, and the marking end may be kept under water or other suitable liquid to prevent the ink from drying either in the tube or round the outside of it when the instrument is not in use, and when it is not convenient to stop the flow of ink through the tube when not in use, the ink which flows is conveniently made away with by being discharged into a large enough vessel of water or other suitable liquid. Part of the mechanism consists of a geometrical slide by which without any unclamping and clamping and without disturbing the connecting fibre and suspended coil the syphon may be raised out of the ink bottle, left to itself till the vessel of solvent is put in position to receive either end of the syphon, and lowered again. The motion of the frame bearing the syphon is to be in a circle having for a centre the point of attachment of connecting fibre to suspended coil. By "geometrical slide" I mean a slide fulfilling the geometrical conditions described for the sliding one of the four quadrants of my quadrant electrometer in the description of that instrument published in the British Association Report for 1868, but in the present case by cutting the V grove along a circular arc I have made for the first time a geometrical slide giving circular motion.

16. My next improvement consists in applying oil, or paraffin, or grease, or varnish, or other suitable coating round the outside of the syphon or tube near its marking end to prevent the ink from spreading by cohesion from that end along the outer surface, and so impairing the delicacy of the marking.

17. My next improvement consists in giving a slow motion to the paper driving gear readily substituted for the quick motion used for

recording, so that when no signals are being recorded the paper may continue to move slowly past the marking end so as to carry away the ink spurted continuously from the tube by the electric discharges. This arrangement tends to prevent the clogging of the tube without unnecessary waste of the paper. The details of one method for executing this improvement are described in § 35 below.

18. My next improvement consists in driving the paper and the replenisher by an electro-magnetic engine instead of by a spring or weight.

19. My next improvement consists in constructing this electro-magnetic engine so that soft iron armatures placed on the wheel, and attracted one after another by an electro-magnet are parts of the carriers used in the induction apparatus or "replenisher" employed to produce the series of rapid electrical discharges spurting ink from the syphon.

20. My next improvement consists in details of great importance regarding the make and break mechanism for the electro-magnetic circuit of the engine including a method of adjusting the duration of the current, and the times of making and breaking in respect to the position of the soft iron armatures relatively to the electro-magnet. The contacts are broken by the action of a cam wheel upon a steel or agate pin, and are made by return force of elasticity. This cam is of such dimensions, the electric contact pieces are so placed, and the pin, spring, and moveable contact piece are so constructed that a very gradual slip in the lifting action of the cam, and a very small whole amount of lift suffices to produce the break, and that the smallest sufficient mass of matter is moved by the action, conditions all violated to the great detriment of efficiency in all electro-magnetic engines of the same general plan hitherto made or described so far as known to me. The moveable contact piece is a short piece of stout platinum wire soldered near one end of an approximately straight steel spring. This end of the spring is reduced to a round pin in line with the middle line of the spring, and projecting to a short distance beyond the platinum contact piece. The other end of the spring is attached to a fixed insulated piece of metal with which it is in metallic communication, and through which it forms part of the circuit which is completed when the moveable contact piece is allowed to press on the fixed contact piece by the projecting pin being freed by the cam. The line of the spring is parallel to the axis of the electro-magnetic engine and its plane of motion passes

through this axis. The cam lifts the projecting pin to break contact, and leaves it free at the proper times to make contact by its own elastic force. The spring, which is approximately straight either when making contact or when lifted through the small space of the cam's action on it is under considerable elastic strain. When dismounted and allowed to take its unstrained shape it is curved; in this state the curvature ought if the flexual rigidity of the spring is uniform throughout to be approximately in simple proportion to length along the curve from the end which is fixed when the spring is in position. This condition is easily fulfilled with sufficient approximation to accuracy by giving the spring a proper set so that when mounted it is found to be nearly enough straight, and to press with sufficient force against the fixed contact piece to secure good contacts. The disposition described above according to which the motion of the spring is in a plane perpendicular to that of the cam, the form of the spring straight, and the point of pressure of the cam very close to the moveable contact piece, secures the great dynamical advantages stated above. The cam may work in a vertical plane, and its lower edge dip in an oil vessel or press lightly against a soft substance moistened with oil, or it is so arranged that oil may with great ease be applied to its rim by the operator in charge of the instrument. A steel screw acting on a jointed arm, which bears the contact pieces is used to increase or diminish the distance between these and the axis of the cam sufficiently to adjust the duration of the contacts. Another simple mechanism allows the block carrying the contact pieces and that first adjusting screw to be moved round an axis nearly enough coincident with that of the engine shaft sufficiently to adjust the time when the contact is made so as to obtain the best action, or the cam itself is adjustable on the engine shaft. These details will be fully described by reference to the Drawings which will accompany the Complete Specification.

21. My next improvement consists in mechanical details regarding the bearings of the electro-magnetic engine. The pivots of its main shaft are of a peculiar form, which will be shewn in the Drawings; each of these is supported on a single fixed roller, and is prevented from slipping or rolling off this roller by two smooth parallel guides, between which it plays easily. Motion of the shaft in the direction of its axis is checked by two hard plates fixed perpendicular to its axis at a distance asunder slightly greater than its length. The friction rollers, each of

one piece of steel, are also of peculiar shape, which will be shewn in the Drawings; they are kept in position by end plates, as described above for the main shaft; each of them dips in an oil vessel, and carries oil round sufficiently to keep its own pivots and the pivots of the main shaft constantly oiled. The guiding cheeks of the main shaft and the bearings of the friction rollers are so placed (as will be shewn in the Drawings) that during the action of the instrument the pivots of the main shaft press each of them only on one of those guides and on the friction roller, but with much more force on the friction roller than on the guide. It need press with no more force on the guide than to prevent it from leaving that guide and moving over to the other under the influence of the varying force to which it is subjected through the successive electro-magnetic attractions.

22. My next improvement consists in a hanging shaft for transmitting motion and reducing the speed from the engine to the paper driving shaft. A smooth V grooved pulley borne by the main shaft of the engine, or simply a groove cut in this shaft, drives an endless cord on which hangs a large pulley below. This pulley is attached to a long shaft, and carries a smaller pulley at a considerable distance from it; this smaller pulley is hung on a V grooved pulley attached to the paper shaft; the portions of the whole weight thus hung on the two cords must be each enough, but should not be more than enough, to secure the requisite driving forces of friction; this condition I fulfil by fixing to the hanging shaft in the proper position a weight of proper amount. To give the requisite steadiness to the hanging shaft pivots of the form to be shewn in the Drawings, being similar to those of the pivots of the main shaft, are guided each by one vertical guide, and checked each by an end plate; or only one of them is checked by an end plate, which is so placed as to press it slightly, but constantly. The vertical guides are so placed that when the machine is not running they are just touched and pressed with very little force by the pivots. The sides of the pivots touched by the guides should be so chosen that if the paper shaft is turned in the proper direction by force applied to it, and the engine shaft thus compelled to move round, the pivots of the hanging shaft shall jump off from the guides. Thus it is secured that when the engine drives the whole mechanism the pivots of the hanging shaft shall be pressed gently against their guides with greater or less force according as greater or less resistance is opposed by the paper shaft.

This next improvement, besides rendering the loss of energy by friction very small, has the great subsidiary advantage of affording means for the engine to do work on the paper shaft without transmitting mechanical vibrations to an inconveniently great degree, or to so great a degree as would be done by any of the mechanisms commonly known in the engineering of large or small machines. The cords should be very flexible, and as the wear and tear is greatly diminished by my present improvement, they may be simply stout silk cords, each with its ends tied by an ordinary reefing knot. If either cord is crossed it is prevented from rubbing against itself by arranging that the hanging shaft is not parallel to the other shaft concerned, but deviates from it somewhat in azimuth.

23. My next improvement consists of two parts. (1.) A means for regulating the speed and diminishing the injurious spark at the break of the electro-magnetic engine. (2.) A means of augmenting the maximum speed attainable with a given battery, and of attaining better economy of the electro-magnetic work.

(1.) I regulate the speed by graduated resistance coils, arranged to be applied very readily to the coil of the driving electro-magnets, either as shunts or as added resistances, and taken off, so as to produce the desired adjustment. I keep on a weak permanent shunt to diminish the spark. This and the regulating shunts are for the same purpose each made of wire doubled on itself through its whole length, taking advantage of a principle discovered by Faraday in the commencement of his experimental researches in electricity.

24. (2.) I diminish the inductive action tending to produce the spark, and increase the maximum speed and the efficiency by taking advantage of another principle discovered by Faraday, and dividing the soft iron core into parts separated from one another by thin layers of varnish or other non-conductor, in surfaces cutting across the lines of flow of the currents which are induced in the iron when this improvement is not made. One way of executing this improvement is to make the core altogether or in part of varnished soft iron wire, which, however, has the disadvantage of leaving considerable interstices not occupied by iron. I prefer a smaller number of pieces fitting approximately to one another.

25. My next improvement consists in regulating the speed of the paper shaft with chronometric accuracy, and I add appliances to

mark time accurately on the paper itself and to shew time as is done by the hands of a clock. A shaft supported on friction rollers is placed in prolongation of the paper driving shaft and is carried round by the latter by means of a pin working in a radial slot so as to be easily removeable and to be when at work not liable to lock or jam even if its axis is not rigourously in line with that of the paper shaft. It will be called for brevity the chronometer shaft. It rests on two friction rollers attached to one long shaft (which may be supported on ordinary bearings) below it. It bears upon these rollers by two other rollers coaxial with itself. One of these other rollers is rigidly attached to the chronometer shaft. The other is attached to a tube mounted on this shaft by means of a collar at one end of the tube and a bearing at its other end for one terminal pivot of the chronometer shaft. The four rollers are of such dimensions as to give the tube such a differential motion that it goes round somewhat faster than the chronometer shaft. I find that something from five to ten per cent. faster than the chronometer shaft gives good results. A second tube fitting by a collar at each end of the chronometer shaft is placed close to the first mentioned tube, and is carried round by a spring clip pressing it externally or by other suitable friction gear. This second tube when unchecked is carried round as if rigidly connected with the first tube, but it can be checked with ease so as to be altogether stopped at any time. When it is released the friction is sufficient to set it very suddenly in motion again with the same speed as the first tube. The second tube carries one or more arms which act upon a pendulum through a pallet or pallets after the manner of the teeth of a dead beat escapement wheel. They keep the pendulum vibrating, and at each impact on the dead face of the pallet the rotation of the tube is checked sufficiently to prevent more than one arm from passing for every period of the pendulum. Thus if a "half seconds" pendulum be used, that is to say, a pendulum whose period is one second, and if the second tube is to turn once round in twenty seconds, there must be twenty arms. These arms might be rigid like the teeth of an ordinary escapement wheel so that the arrangement would simply be an escapement wheel loose on the chronometer shaft and influencing it in the manner described below. But I prefer making the arms elastic to prevent damage in case of any of them being taken aback by the pallet and also to regulate the motive force applied to the pendulum by each arm in escaping the pallet. There may be either two pallets arranged just like those of the ordinary anchor of the dead beat escapement, or there may be only one pallet, one side of the anchor as it were being cut away. When only one pallet is used the plane of motion of the arm may very conveniently be perpendicular to the plane of motion of the pendulum which gives an arrangement preferable in point of simplicity to other more common or obvious transformations of the general plan described above. A spring carried round by the escapement wheel is kept in metallic communication through a metal ring or disc, or cylinder, or grooved pulley rigidly attached to the first or second tube and a spring pressing upon it with a fixed wire. Another fixed wire is similarly kept in communication with a metal ring rigidly attached to the chronometer shaft, a rim composed partly of metal connected with this ring and partly of insulating material rigidly attached to the chronometer shaft is touched by the spring carried by the escapement wheel. By insulating materials properly placed these two wires are cut off from metallic communication through the moving parts which have been described except when the elastic arm carried by the escapement wheel is in contact with the metallic part of the rim on which it presses. One or other of them may be in metallic communication with the chronometer shaft and the two tubes; but I prefer insulating all the pieces of metal which are in connection with either of the fixed wires by vulcanite or other proper material so as to prevent metallic communication between them and the shaft and tubes. The two fixed wires are connected to the two ends of the coil of the driving electro-magnet by electrodes of proper resistance to fulfil the following condition:—When the second tube is in such a position relatively to the main shaft as to make contact the coil of the electro-magnet is shunted so as to reduce the driving power sufficiently for the purpose of regulation. For example if the resistance in the electrodes and moveable contact pieces which have been described are infinitely small the driving power would be altogether stopped when the contact referred to is made; but this would be a more abrupt controlling action than is desirable. In most cases I prefer to arrange so that the resistance in the shunt shall be several times greater than the resistance in the electro-magnet, and I secure that the controlling action shall be sufficient by adjusting the rate approximately by the method described in (§ 23). All that is necessary to secure this condition is that without the regulating shunt the chronometer shaft would attain a speed greater than the proper speed, but that when the shunt is applied the power is insufficient to maintain the proper speed.

26. To shew minutes and hours and mark them on the paper I attach a toothed wheel to the paper shaft or to the subsudiary shaft described in § 35, and by it drive a train of shafts at the successive slower speeds desired; thus the paper shaft going once round in a third of a minute the next shaft may go once round in five minutes, the next once round in an hour, and the last once round in twenty-four hours. The five minutes shaft shows time to the nearest second on a properly divided disc either turning with the shaft or fixed. The hour shaft shows the minute, and the twenty-four hour shaft the hour reckoned from 0 to 24, astronomical reckoning. The train may be set to correct Greenwich time (telegraphed through the lines at sufficient intervals) by turning round the paper shaft which is permitted with sufficient freedom by the friction gearings described above. The twenty-four hours wheel carries steel stamps at equal intervals to mark the figures from 0 to 24 on the paper. A hammer whose upper acting surface is mounted with leather, india-rubber, or other soft material is so mounted and so influenced by a spring that it rests when undisturbed at a very short distance below the rim to which these stamps are attached, but is movable downwards or upwards. It is depressed gradually by a snail or pin carried round by the one hour shaft, and is suddenly released exactly at the end of each hour, when it flies up beyond its position of equilibrium and strikes the paper against the hour stamp which is passing at the time. The paper is so led before it reaches the drawing drum that it passes between the hammer and the stamping rim, and so is always in position to receive the impression of each stamp by the blow of the hammer. Or the figures may be printed upon the paper in ink by a proper arrangement for inking each type before it reaches the proper place. When the plan described in § 36 is used the hours and half hours from 0 to 12 are marked on the paper. If desired the minutes, or every five minutes, may be also stamped on the paper by types attached to the one hour shaft and a hammer worked by the five minutes shaft. A short knife edge projecting very slightly from one of the rims of the paper drawing drum marks its revolutions on the paper and subdivision of the space from mark to mark [which may correspond (§ 26) to twenty seconds uniformly or (§ 36) to twenty seconds of receiving or five seconds of sending] readily gives time to the nearest second.

27. I use the same piece of mechanism or other mechanism similarly regulated to draw perforated paper, so as to make the signals required

to send messages through the line. By a proper punching apparatus the messages to be sent are to be stamped upon the paper so as to give Morse signals, or Steinheil signals, or signals of any other kind. Each message or set of consecutive messages may be stamped on the ribbon of paper continuous with that which is used in receiving signals from the other end in such a position as to enter the wheelwork at the time arranged for the remote station to commence receiving. But especially for recommandé messages it may be desirable to stamp the message to be sent on separate paper in order to give time and convenience for thoroughly verifying before sending it. In such cases either a separate machine may be used or the ordinary receiving paper may be cut and the special message gummed to the part running into the wheelwork. By this arrangement one continuous slip of paper delivered from the wheelwork will contain the syphon records of all the received messages, and (§ 28) all the sent messages and the perforations by which the sent messages have been sent, and (§ 26) the impressions showing the hour, minute, and second at which any part of any message passed the syphon accurately marked in Greenwich time. Thus the paper delivered from the instrument contains a permanent record of every signal which has passed through the line in either direction in a form thoroughly convenient for subsequent verification or comparison. The superintending officer at the sending station can make certain that each message is stamped on the sending paper with absolute accuracy, also by the syphon record of the sent signals he can make sure that no failure in the battery or electric contacts or connection with the line has vitiated the transmission of the message and that each individual component signal has been accurately delivered into the cable. Hence no repetition even for recommandé messages or figures will be necessary unless some failure of the record at the other end leaves doubt as to some of the signals in the message there received.

28. To adapt the syphon recorder to write sent signals as well as received signals on the continuous ribbon of paper I apply a powerful shunt on the electrodes of the movable coil. A shunt whose conducting power is from 20 to 50 times that of the suspended coil answers well in most cases of long submarine signalling. To do this readily I add a shunting contact to the switch used to alter the connections from sending to receiving. To make sure of the several contacts thus required in the switch I have made a switch of peculiarly simple con-

struction. It consists of contact studs and a stout bar of brass or other suitable metal pivoted on a round steel rod passing through a hole about its middle and fixed horizontally. The bar is pressed horizontally near its middle by a strong spring on one side and is resisted by contact pieces or vulcanite pressing its opposite side near its ends. One end is put down for sending and up for receiving. In the first position each end makes a metallic contact; in the second position only one end does so. The cable is constantly in connection with the bar through the central spring. The usual middle (or discharging) contact if desired for any purpose is given by a stud, across which one end of the bar slips in being switched up or down.

29. When the instrument is used for sending by aid of perforated paper the paper may be drawn by the drum and roller merely in the ordinary manner. To make the signals I use the following system of contacts:—The paper is drawn firmly over a fixed smooth surface, and one, two, or more springs press upon the paper except when a hole in it allows them to press upon that fixed surface. Insulated metal studs carrying the proper electrodes are fixed with their faces flush with that fixed surface, so that when apertures in the paper permit it contacts are made by the pressure of the springs on these studs. To make single current signals as in the Morse system I use two springs, one of which when in contact with its stud connects the line with the earth, the other the line with the insulated pole of the battery.

30. Or I use only a single contact spring, and I keep the near end of the line in connection with the earthed pole of the battery through a wire of sufficient resistance, and the contact spring when in contact with its stud connects the other pole of the battery with the line. If the resistance of the battery is small in comparison with that of the wire resistance just referred to, the fact of the line being constantly connected with the earth through this wire resistance will not greatly diminish the potential produced in the line by the battery from what it would be were the resistance of the wire infinite.

31. Similarly when I wish to make Steinheil signals (such as those hitherto used in long submarine cables according to my system) I employ three contact springs, which when their contacts are made connect the cable respectively with the earth, or with the positive or with the negative pole of a battery, the middle of this battery being earthed.

32. Or I use only two contact springs, and I keep the two poles of the battery constantly connected with one another through a wire of sufficient resistance, the middle of this wire being constantly connected with the cable and the middle of the battery with the earth. This method (§§ 30, 32,) besides its great simplicity has the advantage of diminishing much the lost time experienced in passing from one to another of the contacts made in more ordinary methods of telegraphic signalling. It is particularly valuable also for the Steinheil signalling by hand hitherto practised on long submarine cables, inasmuch as it does away with the upper contacts, which in the ordinary keys have been found liable to fail, and gives more regular and more sharp signalling.

33. When I use signals produced by applying to the near end electrifications of several different degrees of potential (as specified in my Patent of 1858, No. 329), I use either of the methods just described, but I prefer the latter (§§ 30, 32,) according to which the two poles of the battery are kept connected by a wire of sufficient resistance. Electrodes lead from several points of this wire to the contact springs or studs, the studs or springs being kept connected with the cable, and one point of the battery, generally its middle, is kept connected with the earth. Perforations in the paper along any one, two, or more lines parallel to its length allow contacts to be made with regularity for the Morse, Steinheil, or other system used. Sometimes instead of drawing the paper in the manner described in (§ 29) it may be desired to draw it more definitely, so that each single perforation shall pass the contact piece at an instant when the wheelwork has a definite position. When this is desired I arrange as follows:—The paper drum is definitely geared by toothed wheels to turn with the same tangential velocity as a roller of diameter equal to its own or half its own, or conveniently commensurable with its own. The paper passes between the drum and this roller, but is not pressed firmly between them; it is drawn by teeth in one of them projecting into hollows of the other. When it is desired to record the sent signals of the syphon on the perforated paper itself which is used for sending, and to have the same drum and roller arranged to draw the paper when the instrument is used for receiving the perforations by which the paper is drawn may conveniently be made in two rows very near its two edges. The drawing teeth and hollows must lie on corresponding circles of the drum and roller. The receiving paper may be prepared with perforations, so that it shall be drawn through the instru-

ment by teeth just as is the paper used for sending. Paper prepared for sending must have another row or two or more other rows of perforations punched upon it in proper positions to produce the signals. These positions must be made by the punching machine quite definitely in relation to the perforations designed for the drawing teeth. Or if it is desired to avoid the necessity of perforations in the paper used for receiving, the roller used in sending having teeth projecting into hollows in the main paper drum may be replaced by the ordinary roller pressed firmly against the drum whenever the instrument is adjusted for receiving instead of sending; or the same drum and roller may be used provided the drawing teeth are of proper shapes and magnitudes not to damage the paper nor impair the regularity with which it is drawn past the syphon. The same wheelwork can be used for a curb key to be worked by hand; thus a disc on the same shaft as the paper drum is notched in its circumference properly, and acts as a cam upon a spring contact piece or pieces.

A hand key (double for the Steinheil system) is used to prepare for the contacts. When either finger piece is pressed down it does not instantly make its contact, but presses a spring ready to make it as soon as the cam permits the contact piece to fall. The operator perceives by ear, or touch, or both, when the contact is made, and holds on his finger till he perceives the cam to have unmade it again; or else a simple mechanism holds on the contact when once made until the proper instant for terminating it. One plan for this mechanism is to have the cam cut with a circular groove, into which a pin enters when permitted by the notch, and which holds the pin down until a second notch allows it to rise. But many other mechanisms can readily be devised according to the dimensions and speeds convenient in the actual instrument and its particular application.

35. To draw the paper at the quicker rate proper for sending (when the rate found convenient and economical of paper in receiving does not suffice for sending) I make the drawing wheel or drum movable freely relatively to its own shaft round their common axis. By a ratchet wheel and pawl it is prevented from running backwards relatively to the shaft, but it is free to move forwards. The ratchet wheel may be either very fine, or it may be infinitely fine with the pawl pressing on it at an angle less than the sliding angle, so that when the drum is running round faster than the shaft there may be no disagreeable noise. By toothed

wheels attached to the shaft and to the drum, and by a parallel auxiliary shaft carrying wheels geared to these, the drum is made to run faster than the shaft. This secondary shaft by well known simple mechanical contrivances when it is ungeared the pawl carries the paper driving drum at the same rate as the shaft; when it is geared it carries the drum forward faster than the shaft at whatever rate it is determined upon as suitable for the purpose of sending. This method has the disadvantage of getting up the speed for the quick motion by gearing from a lower speed, while both are lower than the speed of the driver, to escape which I have devised the following (§ 36) alternative but generally preferable plan.

36. To give the paper a quicker speed when wanted for sending without intervention of a lower speed, and at the same time to leave the time marking train undisturbed in its rate, I use an auxiliary shaft carrying three cog wheels; one of these is driven by a toothed wheel fixed to the paper driving shaft, another drives the clock train, and the third when in gear drives a toothed wheel fixed to the paper driving drum, which is arranged to run round freely upon its shaft. At pleasure the two last-mentioned toothed wheels may be ungeared from one another, and the paper driving drum immediately after clutched by the shaft on which it runs, so that it may run in the same time with this shaft. For example, let the quick speed be four times the slow speed, let the slow speed be one foot of the paper per minute, and let the circumference of the paper driving drum be four inches, the paper driving shaft must go round once in five seconds, and the drum as above once in twenty seconds. It is then convenient to make the auxiliary shaft run once round in ten seconds. If a clock train the same as that above described (§ 26) is still used the slowest wheel goes once round in twelve hours, and the dies are arranged to mark hours and half hours on the paper from 0 to 12.

37. To produce the perforations in the paper used for automatic sending I have designed an instrument differing in some essential particulars from any of the punching keys hitherto made or described, so far as known to me. It consists of (1) two rollers to draw the paper geared, so that their circumferences run accurately at the same rate however suddenly the motion be started or stopped; (2), mechanism for turning these rollers through proper angles, and stopping them accu-

rately in proper positions; (3), a punching key or punching keys to make the perforations which give the signals.

38. When the simple plan of (§ 29, 33) is used the two rollers may draw the paper in the usual way, but if so they must be pressed very firmly on the two sides of the paper, so that the portion of it in the place where the punching is performed may start and stop instantly with the rollers. To secure this condition I apply sufficient frictional or tangential resistance to the paper before it reaches the rollers to draw it tightly over the place where the punch acts.

39. When the paper is to serve for the system of (§ 34) the rollers still forcibly pressed together are provided respectively with teeth and with hollows very slightly larger than the teeth to cut the perforations by which the paper is drawn (§ 34) through the sending machine.

40. The mechanism for moving the rollers is either on the same general plan as the lever windlasses so commonly used in ships, or it may be on the principle of the dead beat escapement, but in this case there must be motive power acting (as on the escapement wheel), so that the rollers always tend forwards. For stopping the rollers exactly in the proper position every time before the punch acts I use either a sustained resisting force or a sustained forward force to maintain steady pressure against a pawl or other stop, and steady pressure between the teeth of the gearing concerned in holding them. When this is done by a sustained resisting force elasticity or gravity must be used to draw the paper back by the force (§ 38) used to keep it tight. A key moved to and fro by hand acts on the mechanism, so as by each motion to and fro to carry the paper forward through a definite space without causing it to be perforated. This key I shall for brevity call the space key.

41. I perform the punching by a lever acting on a properly shaped die. When greater accuracy is desired for the dimensions of the aperture than can be otherwise obtained I add a movable guard round the die according to the following description:—A piece of metal leaving an aperture of the proper shape and dimensions is pressed down on the paper immediately before the die reaches the paper. The die fitting like a piston in this aperture is pressed through this aperture against the paper, and into another aperture in a fixed piece of metal on the far side of the paper, fitting as closely to the die and forming as exactly a prolongation of the first aperture as good workmanship can make it to fit without giving rise to the great resistance by the motion of the die.

Thus just before the die acts the paper is held firmly between two solids close round the piece of it that is to be cut out by the die. The die returns through the perforation before the paper is released. To obviate difficulty in detaching the fragment of paper cut out by the die I sometimes make the die hollow with a rod sliding through the hollow space which it nearly fills; this rod after the die has made its cut protudes and presses away the fragment of paper. A single pressing surface acting on properly arranged springs produces these three motions, and its return allows the inner rod, the die, and the guard to return in order. The return of the lever which acts on the die gives the rollers the motion or permits them to take the motion required to place the paper in the position for the next action of the die. When as for the Steinheil system of signals or higher multiple systems (such as those described in my 1858 Specification, No. 329) two or more dies are required, I use a separate lever for each die, and arrange that the depression of any one alone of these levers draws down one common lever or moves one proper piece of mechanism, the return of which moves the paper into the proper position for the next perforation. For very rapid action the tendency of the rollers and paper to run too far may be not completely checked by the arrangement described above, but it secures that they are drawn back into correct position before the punch acts, but the forces concerned are necessarily large. Hence very strong material must be used for the different moving parts, but the massiveness required to give the necessary strength itself involves the action of much larger forces than are necessary merely for the operation of punching the paper, I therefore prefer an altogether different plan of instrument for rapid action, and have therefore invented the following:— To avoid circumlocutions I shall suppose the Steinheil system of signalling to be adopted, and the signalling perforations to be in two rows, and further I shall either suppose that there are no other perforations than those in the two rows, and that the paper is drawn along both in the punching instrument and also afterwards in the automatic sender merely by the pressure of a drum with milled rims, or I shall suppose a row or rows of perforations at equal intervals to be made in the paper for the purpose of drawing it through in the automatic sender as herein-before described. The same plan with obvious enough changes of detail is applicable to perforate the paper for other modes of signalling which may be desired in any case. I use three levers which according to usage will often be called keys. One of them I shall call the space key another the dot key, and another the dash key, the recent submarine usage having applied the name of dots and dashes in submarine signalling to left and right motions of the marker. When any one of the three keys is depressed and allowed to rise it causes a certain shaft which I shall call the revolver to turn through a certain angle either a complete turn or any sub-multiple of a turn. I shall describe the details on the supposition that it is a complete turn. This shaft during a definite part of the revolution acts on the paper drum, so as to cause it to commence gradually moving, and after having attained a maximum velocity to gradually cease moving when it has reached a perfectly definite position. This effect is produced by a pin carried round by the revolver so as to enter a radial slot in a disk coaxial with the paper drum moving radially when it enters and leaves the slot. To make sure that the paper drum does not move except through the action of the revolver a clutch checking it in exactly the proper position may be appended. Further this clutch may be so arranged that if through want of absolute truth in the mechanism the position in which the paper drum is left by the pin be not precisely correct, the drum may be brought forward or backward so as to bring the paper to its precisely correct position ready for the punch. Lastly, to make sure of the very definite action of this clutch it is desirable that the surfaces of the V notch on which it acts should be inclined at an angle smaller than a right angle, or at most not much greater than a right angle. To get the best result I therefore add an application by which the clutch is lifted through the action of the key shortly before the instant when the pin of the revolver enters the radial slot. But a good result may be obtained more simply by inclining the faces of the V differently to the radius through their intersection, and arranging the line of motion of the clutch so that it cannot jam either when it is pressing the wheel back, or when the wheel by moving forward lifts it. The mode in which each key acts on the revolver may be as follows:—The key being supposed to be approximately horizontal and the motion of each acting part approximately vertical. When the key is pressed down it presses upon a treadle as it were, which like that of a lathe works on the revolver shaft through something less than half of its revolution, which is continued and completed through inertia. The clutch dropping into the V notch stops the revolver shaft sharply enough in its proper position for the next action of any of the keys. The notch may be sufficiently obtuse to allow the clutch to be lifted as by a cam by one side of the V when a fresh action of one of the keys turns the revolver. The inertia by which a complete revolution of the revolver in a sufficiently short time is secured is that of a fly wheel loose on the revolver shaft but acting on it through friction. This friction is best produced by a cord having its two ends attached to arms on the fly wheel and itself wrapped more than once round the revolver shaft. The arm to which the after end of the cord is attached is rigid, the other is a spring tightening the fore end of the string with a force approximately equal to the tangential force required when the fly wheel draws the revolver after it. This arrangement causes when motive power is applied to the shaft a much greater force than that of the spring to act on the rigid arm and accelerate the fly wheel. Any one of the three keys pressed down alone acts through the treadle in the manner described above upon the revolver. The space key does nothing else. Each of the other keys in being depressed punches the paper and rises by force either of a stout spring or of the treadle or of both, the dot key makes its perforations in the proper line of the dots, the dash key in that for the dashes. The punches may be rigidly attached to the keys, or they may move in geometrical slides pressed down to cut the paper by the key and returning by springs. I prefer to connect each punch rigidly with its key. The pin on the revolver which drives the paper shaft is so placed relatively to the crank pin by which the treadle gives motion to the revolver that the paper is at rest for the whole time during which the lowest part of any of the punches is below the upper surface of the paper, it being supposed that the punches move downwards in cutting.

42. The interval which distinguishes the beginning of a new letter, number, or other signal from the beginning of an additional constituent signal of an incomplete compound letter or signal will be called for brevity the letter space. Similarly I shall call the word space the excess above the letter space which is used to distinguish the commencement of a new word or group from the continuation of an unfinished word or group. It is generally convenient to make the word space equal to the letter space. To save time in sending a message I sometimes make the letter space shorter than the interval between the consecutive individual component signals of which compound letters, or signals, or numbers are compounded. For example, I make the letter space half that of the component signals, and to do so I arrange that the space they (§ 40) shall move the paper through just half the space that it is moved through by the return action described in (§ 41) when this system is followed punctuation may be sent in such a manner as

to promote clearness very much with but very little loss of time. Thus a comma may be given by adding a space equal to the latter space, to the word space, a semicolon by adding the same to the comma, and so on. When a semicolon, or colon, or full stop, or mark for a new paragraph is sent as a definite signal and not merely to promote clearness in the reading of a messuage the comparatively elaborate groups of signals prescribed for them in existing codes may still be used. Or the comma space may be made double the letter space or word space, the addition to the comma space for the semicolon equal to the comma space, the addition to the semicolon space for the colon equal to double the comma space, and the addition to the colon for the full stop equal to double the comma space. This with the accuracy of spacing produced by automatic sending with accurately executed perforations and with the syphon record of received signals will give thoroughly distinct indications to distinguish precisely which of the stops is meant, and will still be considerably shorter than the signalling of the stops practised at present on long submarine lines according to the Vienna code, with lefts and rights substituted for dots and dashes. But when the curb key method by perforated paper and a cam as described in (§ 34) is adopted the letter space cannot readily be made less than the interval of the component simple signals, and the greatest economy of time attainable without mechanical complications is had by making the letter space equal to that interval. In preparing the paper by perforations to send a message the letter space is produced by a single pressure and return the word space by a second pressure and return of the space key.

43. Each separate rigid solid in the punching machine should have just one degree of freedom to move. I arrange for this in each case by five perfectly different degrees of constraint planned on geometrical and dynamical principles (1) to maintain each degree of constraint with sufficient force to meet the greatest tendency to break it which can occur in the use of the instrument; (2) to oppose rigidity enough against the inevitable elastic deviations from the geometrical conditions; (3) to produce no inconveniently great amount of frictional resistance against the motions provided for. For example, each lever is pivotted on definite V bearings according to the principle used in a transit instrument, and each piece to slide to and fro in a straight line is guided by a "geometrical slide" (§ 15). The details of construction by which these conditions are realized, differ greatly from those of any other

telegraph instruments or ordinary mechanism known to me. They will be fully described with aid of Drawings in the Complete Specification.

44. It is important to have a battery of small resistance which shall be very constant in its action and require renewal but rarely to drive the electro-magnetic engine, to sustain the signal magnet (except when it is a permanent magnet), and to perform the electric work of the rending especially if performed according to the general method of (§§ 30, 33). For these and for general telegraphic purposes I have made improvements on the form of battery described in Thomson and Jenkins' Patent 1860, No. 2047, and commonly known as the "sawdust Daniells" or the tray battery. I use trays of copper or lead or other suitable metal to contain the sulphate of copper, the liquid, and the sawdust or other porous material. I add false bottoms of thin sheet copper or other metal to facilitate the removal of the deposited copper, and the realizing of its metallic value. I apply a coating of paint or varnish or other non-conducting material to prevent the deposition of copper on the tray itself. I solder properly placed contact pieces of metal to the bottoms of the trays outside, I add a wooden frame inside each tray to bear the weight of the zinc and of the superincumbent column when the battery is filled one cell above another. This frame serves also to confine the sawdust or other porous material in a proper place by the clear space which it leaves round itself, and allows the addition of more sulphate of copper in solid fragments and of water to replenish for loss by evaporation, I cast the zinc to be used in the form of flat slabs with ridges or other suitable projections on its upper side to bear the tray next above when there is one, and to present surfaces of zinc always dry for the electric contacts. Instead of copper trays I sometimes use wooden trays lined with lead; the sides of the wooden trays are inclined, and the lead lining is not soldered but simply pressed into shape. The lead holds water-tight, and the wood is of use merely to support the lead and give the stiffness requisite for convenient use. A hole in the bottom of the wood with a copper electrode soldered to the lead above protruding downwards is used to make the connection.

45. I also in some cases provide as a powerful battery for occasional use to remagnetize the signal magnet one of the old forms of battery with large surfaces of zinc and copper close together in dilute sulphuric acid, the plates being let down into the liquid and lifted again as soon as

the desired magnetization is produced. It is not necessary to keep the plates in the liquid for more than a few seconds on each occasion for this purpose.

46. My next improvement in the ink spirting recorder consists in a regulator for electrification of the syphon. When the electric machine used is simply the replenisher described in my previous Specification or that described above (§ 19) I have found irregularities and occasionally temporary failures of the marking to proceede from dischargings of the insulated inductor effected by intermittent connections between the ink in the syphon and the paper with its metal backing. To prevent this I connect the ink with the inductor by an electrode of very high resistance readily adjustable at any time to the observed requirements. To promote speedy electrification of the right kind after any accidental discharge and to secure electrification, positive or negative, whichever may be found to give the better marking, I introduce a dry pile into the line of this electrode. In case of the electrification of the inductor being found so high as to give too much electricity to the syphon I shunt off some of its electricity by another electrode of great resistance (also adjustible to different degrees) placed so as to connect directly the insulated conductor to the uninsulated metal work of the instrument. To further promote the rapid re-electrification of the insulated conductor with the right kind of electrification I put another dry pile in the line of the second highly resisting electrode resistance. A plan which I have found convenient for these adjustable high resistances is a vulcanite cylinder with a deep spiral groove cut in it. A silk or cotton thread attached to the metal shaft bearing this cylinder passes through a hole or groove in the vulcanite to one end of the spiral groove. The other end of this thread is attached to a small metal drum acted on by a spring like that of an ordinary pocket measuring tape. By turning the vulcanite drum the thread is wound round it and pulled out from the metal drum so as to augment the resistance as in Wheatstone's rheostat. When the vulcanite drum is turned in the other direction the spring draws the string round the metal drum and the resistance is diminished. If the smallest resistance thus obtained when the two drums are conveniently placed is found to be too small the part of the thread remaining unwound between the vulcanite drum and the metal shaft of the vulcanite drum may be impregnated with salt or it may be even replaced by fine metallic wire. If it is found that positive electrification of the syphon gives better marking than

negative electrification the positive end of each dry pile must be placed towards and the negative end from the insulated conductor in the two electrodes described above, or vice versa if negative electrification of the syphon is desired.

47. My next improvement consists in placing all the resistance coils used (whether as shunts or as added resistances) for regulating the electromagnetic engine or the signal magnet in such positions that the head generated in them shall tend to dry the reuniting parts of the replenisher and electrostatic system generally used to produce the writing by the syphon. To promote this object and to guard against the settling of dust and soot on surfaces electrified directly or indirectly from the action of the replenisher as well as to guard against accidental mechanical damage to the syphon, fibre, &c., and to keep the clockwork clean I enclose all the moving parts and highly electrified parts in a case chiefly of glass to allow the action to be readily seen and the signals to be read if desired direct from the point of the syphon.

48. I also construct the syphon recorder with proper variations, such as increasing greatly the number of turns in the suspended coil (and farther if need be the power of the signal magnet) to render it adequate to supersede my marine galvernometer for testing cables at sea, with the advantage of recording the test at every instant.

49. The moveable coil suspended in the magnetic field in the manner described in (§§ 1, 4, 5,) may also be employed to make relay contacts in cases in which a relay is used. I arrange to make these contacts by a metallic contact either carried directly by the moveable coil or moved by a lever or other proper mechanism worked by a fibre or connecting link attached to the coil. I prefer a lever supported by a stretched wire on the same plan as the support of the syphon. The connecting fibre is kept tight in the manner described in (§ 7). The bearing wire forms part of one of the electrodes leading to the contact piece.

50. I will now proceed to describe further my improvements in mechanism for drawing telegraphic receiving paper at a uniform rate, together with other improvements in clocks generally. I arrange by proper mechanism to produce independently of the pendulum an approximately uniform motion of the whole train of wheelwork as approximately the proper rate with provisions for adjustment, by which precisely the proper rate or any other rate within considerable limits on either side the proper rate may be readily given at any time. By peculiar

mechanism I arrange that when the instrument is adjusted to any speed within certain limits and left to itself it will of itself vary the adjustment so as to augment its speed to something decidedly above the proper speed. This automatic change of the adjustment may be gradual or it may be simply from one grade to another, or it may be from one grade to several other grades of higher and higher speeds. Lastly, by a movement geometrically comparible with Graham's dead beat escapement I arrange that a certain shaft or wheel turned by the mechanism shall keep a pendulum vibrating, and shall be prevented by the pendulum from going round on the whole faster than to allow one tooth or arm to pass during each period of the pendulum's motion, this wheel or shaft having any number of teeth or arms which correspond geometrically to the teeth of the ordinary escapement wheel. One such tooth or arm suffices, and for some purposes is preferable to any greater number. The tooth or arm may be rigid and rigidly attached to the shaft or wheel, which for brevity I shall call the escapement wheel, but I prefer to make it elastic or to connect it elastically with the escapement wheel to obviate damage in case of its being accidentally taken aback by the pallets when the clock is being set in motion or when it is imperfectly adjusted, and also to regulate the amount of the working force with which it acts on the pallet when in regular operation. When not touched by the pallet the escapement wheel is carried by a differential motion at a rate somewhat exceeding that of another shaft which I shall call the chronometer shaft, and which I generally find it convenient to make coaxial with the escapement wheel. But this differential motion carries the escapement wheel only by force of friction, and at any time the escapement wheel which may be stopped by the application to it of a sufficient resistance to overcome this friction. The action of the pendulum ensures the correct rate for the escapement wheel. The adjustment described in general terms above acts so that when the chronometer shaft runs at a speed lower than the average speed of the escapement wheel the resistance is diminished or the moving force is increased so as to augment the speed of the chronometer shaft. But when on the contrary the chronometer shaft gains on the escapement wheel the adjusting action adds resistance or diminishes the moving force, and so diminishes the speed of the chronometer shaft. Thus it is secured that the chronometer shaft shall have the same average speed as the escapement wheel, but it moves without stopping and at a very approximately uniform speed through the whole period of the pendulum instead of being brought to rest once or twice in the period of the pendulum's motion as is the escapement wheel. The chronometer shaft is connected by toothed gearing with a train of wheel work, by which motion is imparted to the hands, discs, or counters required for marking time or for producing any accurately uniform motion for which ordinary clockwork is sometimes used, as, for instance, moving an equatorial or drawing telegraphic receiving paper at a uniform rate, or giving the uniform motion required in sending upon any plan of automatic telegraph signals. When weights are used to drive the clockwork one plan which I have practised for the adjusting action described generally above is to have a screw and nut each coaxial with the chronometer shaft and escapement wheel, one of them rigidly connected with one of these bodies, and the other carried round by the other through tangential friction. When the nut turns in one direction relatively to the screw its consequent motion parallel to the axis augments the speed of the chronometer shaft, and vice versa. And more particularly in these cases I have made the axis of the chronometer shaft and escapement wheel vertical, and arranged that the motion of the nut upwards or downwards shall increase or diminish the elastic force by which the centrifugal pressure of whirling masses against a friction rim keeping them from passing its circle is regulated to such a degree as to give the frictional resistance required to maintain the proper speed. For a clock driven by water power the frictional method just described may be used, but I prefer to apply mechanism to diminish or augment the water supply according as the chronometer shaft gains or loses on the escapement wheel.

51. For a clock driven by electro-magnetism a friction governor may be similarly used or the differential motion may be employed to diminish or increase the driving power from one grade to another, or to several others successively. The latter method I prefer, and among various plans for carrying it out I have found the following very simple one, which I have already referred to in (§ 24) to answer well. The escapement wheel and the chronometer shaft carry one of them a ring, and the other a metallic spring touching the ring. The ring is partly of insulating material and partly of metal insulated from the spring, except when touched by it. The spring and the metallic part of the ring are through complete metallic rings kept permenantly in connection with

two fixed conductors. These conductors are connected with the wire of the driving electro-magnet, either in such a manner that when the spring makes contact with the metallic part of the first-mentioned ring a shunt is applied to the electro-magnet and its power is diminished, or in such a manner that when the spring touches the non-metallic part of the ring the circuit of the electro-magnet is broken. The shunting method has the advantage of being less abrupt in its control and also of diminishing the destructive influence of heat at the places of making and breaking of contacts, both in the engine and in the regulator, and to promote this advantage I double upon itself the wire used for shunt, in order to diminish the quasi inertia of the electricity flowing through it. For the same reason I sometimes apply to the electrodes of the driving battery a constant shunt of wire doubled on itself.

52. I use an improved method or pattern of gear for making and breaking contacts in the electro-magnetic engine, which has great advantages over the methods or patterns in ordinary use in respect to smallness of the dynamic power required, accuracy of the times of make and break relatively to the positions to the running part or parts of the engine, durability of the parts liable to mechanical or electrical wear and tear, and facility for replacing or repairing any part which inevitably wears out. The details of this method or pattern, which cannot be well described without the aid of Drawings, will be fully described and explained in the Complete Specification Drawing. They are of great importance in respect to the practical application of my present Invention. With them I have succeeded in obtaining power enough and durability enough to drive a large tower clock by an electro-magnetic engine of very moderate dimensions regulated by very small and simple clockwork on the plan described above. A very moderate galvanic battery suffices as the source of energy by which I thus replace weights.

53. When an electro-magnet with soft iron core with circuit made and broken alternately is used for the driving power I make the soft iron core altogether or in great part of thin iron wires varnished and pressed close together to obviate the slowness of magnetization and demagnetization and the loss of energy due to electric currents in the iron.

54. For very accurate time keeping I have designed (for use in connection with the preceding or any other plan of escapement) a pendulum with compensation for changes of temperature comparatively

free from the chief defects of the methods for compensation hitherto adopted, which I believe to be, 1st, irregularly varying figure of the surface of the mercury in the mercury pendulum; 2nd, friction of solid on solid, resisting the transformation due to temperature, and so causing it to take place by jumps in the gridiron pendulum; 3rd, more rapid following of changes of temperature of the air and surrounding objects by the uncovered part of the iron rod than by the mercury vessel in the mercury pendulum; 4th, imperfectness of the compensation when the temperature is not uniform up and down the space in which the pendulum moves, a defect which exists in a greater degree in the mercury pendulum than in the gridiron; and, fifth, the impracticability of adjusting the compensation of the gridiron according to results of actual trials at different temperatures. My pendulum consists of a heavy weight (lead preferable to other solids than the precious metals on account of its high specific gravity) attached to a short stiff bar of steel or other suitable material jointed at one end to a long stiff zinc rod or tube, and supported horizontally by a platinum wire attached to it at a point between that end and the weight. The zinc rod and platinum bearing wire are approximately equal in length and are each firmly attached to a solid block constituting the top of the pendulum, which is hung by one or more short springs attached to this block and to a very massive fixed block or very rigid and rigidly fixed frame. Or knife edges may be used for supporting the pendulum, but I prefer springs, and I prefer a large number of fine round platinum or steel wires to flat springs as being less liable to flaws and to imperfect elastic action. When I use more than two bearing wires or springs, I distribute the weight as nearly equally as may be among all by attaching their upper ends to transverse springs, each of which yields considerably to its proportion of weight fixed, and to secure a very definitely fixed virtual axis for the pendulum's motion I use a massive well fixed horizontal bar pressing laterally with a cylindrical surface against the bearing wires with sufficient force to deflect the upper free portions of them through a considerable angle from the vertical, or I bring each bearing wire round the top of a strong horizontal bar and down on the other side and hang upon it a weight equal to its proportion of the whole weight to be borne. The main weight (or pendulum "bob") is adjustable through a sufficient range along the horizontal bar to give the correct compensation for changes of temperature according to practical trial. I use a spring joint in preference to a mechanical joint of any ordinary kind connecting the horizontal bar with the zinc rod to avoid friction of solid on solid, but knife edges might answer and would have the advantage of occupying less space.

55. When it is desired that the clock shall strike the hours, &c., if it is driven by electro-magnetic power I add mechanism by which a weight or spring is wound up by the wheelwork during the time the clock is not striking, to supply energy enough for the striking. Or when water power is available I employ a water power engine to perform the striking. One way in which I execute this is by a cylinder with a piston and valves worked by the piston so that the piston moves to and fro regularly at the proper rate for the striking as long as the valve mechanism is left in gear. The striking mechanism of the clock throws the water mechanism into gear at the right time, and throws it out again when the proper number of strokes has been made.

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